C4 Preliminary

C4.1 General

C4.1.1 Policy overview

C4.1.2 Design information

C4.1.3 Definitions

C4.1.4 Abbreviations and notation

C4.1.5 References

C4.1.5.1 Direct

C4.1.5.2 Indirect

C4.2 General Culvert Design

C4.2.1 Hydrology

Iowa Runoff Chart

In the 1950's, the Iowa State Highway Commission (now Iowa DOT) adapted Bureau of Public Roads' Chart 1021.1, "Highway Drainage Manual", 1950. (BPR's chart was adapted from original work performed by W.D. Potter, "Surface Runoff from Small Agricultural Watersheds," Research Report No. 11-B, (Illinois) Highway Research Board, 1950.) The Iowa Runoff Chart has been widely used by IDOT and the counties since then.

The chart is self-explanatory. However, its use does require the exercise of judgment in selecting the land use and land slope factors. It can be used for rural watersheds draining up to 1280 acres. The Iowa DOT Culvert program utilizes the Iowa Runoff Chart for calculating peak discharges when the drainage area is two square miles (1280 acres) or less.

The following is intended to aid that judgment:

1. Very Hilly Land---is best typified by the bluffs bordering the Mississippi and the Missouri Rivers. This terrain is practically mountainous (for Iowa) in character. Small areas of very hilly land can be found in all parts of the state. Typically, they can be found near the edge of the flood plains of the major rivers.

2. Hilly Land---is best typified by the rolling hills of south central Iowa. Interstate 35 in Clarke and Warren Counties traverses many hilly watersheds. Small areas of hilly land can be found in all parts of the state.

3. Rolling Land---is best typified by the more gently rolling farm lands of central Iowa. Interstate 80 in Cass and Adair Counties traverses many rolling watersheds. Small areas of rolling land can be found in all parts of the state.

4. Flat Land---is best typified by the farm lands of the north central part of the state. U.S. 69 traverses many flat watersheds in Hamilton and Wright Counties. Small areas of flat land can be found in all areas of the state.

5. Very Flat Land---is best typified by the Missouri River flood plain. Interstate 29 is located on this type of land for most of its length. Much of Dickinson, Emmet, Kossuth, Winnebago and Palo Alto Counties are also in this classification. Small areas of very flat land can be found in all parts of the state.

Use the Iowa Runoff Chart only for rural watersheds and the limitations of drainage areas listed below. This equation was developed by finding the best statistical fit to the curve on the Runoff Chart.

For drainage areas, $2 < A < 1280$ acres
$Q_{design} = LF \times FF \times Q$, where $Q = 8.124\ A^{0.739}$
Q is in ft^3/sec
A is in acres

Frequency Factor (FF)

Frequency, years	5	10	25	50	100
Factor, FF	0.5	0.7	0.8	1.0	1.2

Land Use and Slope Description (LF)

Land Use	Slope Description				
	Very Hilly	Hilly	Rolling	Flat	Very Flat (no ponds)
Mixed Cover	1.0	0.8	0.6	0.4	0.2
Permanent Pasture	0.6	0.5	0.4	0.2	0.1
Permanent Woods	0.3	0.25	0.2	0.1	0.05

C4.2.2 Hydraulics

C4.2.3 Culverts in Series

C4.2.4 Bedding and Backfill

C4.2.5 Settlement and Camber

C4.2.6 Minimum Allowable Cover

C4.2.7 High Fill Pipes

C4.2.8 OD Standard Road Plans and Road Design Details

Guidelines for Using the Standard Road Plans and Road Design Details.

The following guidelines should be considered when designing pipe culverts. Pay careful attention to the graphical representation and notes listed in the Standard Road Plans and Road Design Details. A common mistake made when designing culverts is not listing all dimensions in the Remarks space on pink sheets. Also, items such as the angle of bends or DR-121 connected pipe joints are often forgotten and not placed in the Remarks on the pink sheet. These items plus many others on the pink sheet, which are used for site specific information, are necessary to properly complete the culvert tabulation 104-3 in the road plans. Discussion is also provided for Road Design Details 4309 and 4311 for foreslope shaping at culverts.

If the slope of a DR-601 or DR-651 would be steeper than approximately 5%, pipe letdowns are required. If the fall across the roadway is greater than approximately 8 ft or if the fill above the elbow for a DR-611, DR-632 or DR-652 is greater than approximately 10 ft, consider using DR-625, DR-629, DR-632, DR-641 or DR-653 for ease of construction. The gradient of the pipe beyond bend should be less than 1%.

For pipe letdowns (DR-625, DR-629, DR-632, DR-641 and DR-653) with double elbows, the Length "B" portion for letdowns should be approximately parallel to the foreslope. The desirable cover above "B" is equal to the diameter of the pipe. This helps resist uplift forces. The minimum "C" length is 2 ft and the connection between the concrete and corrugated pipes should extend beyond proposed shoulder line. The flowline at this point should be approximately 6ft below shoulder elevation. On the pink sheet, specify concrete pipe in the space (Pipe _____ + ____Aprons). Specify CMP or PEP or UNCL in the space (Flume ______), but revise this space as (CMP or PEP or UNCL ______ + ___Apron). Specify quantity of elbows, degree of elbows (to the nearest degree), and culvert type in the Remarks on the pink sheet.

Concrete pipe class 2000D will be the minimum strength under paved roads. The strength of pipe will be determined per SRP DR-104, "Depth of Cover Tables for Concrete and Corrugated Pipe." .

For all non-NHS highways with traffic counts less than or equal to 3000 VPD, unclassified pipes should be used.

All pink sheet remarks shall be conveyed to the culvert tabulation comments on 104-3, except in those instances where the quantity information is included in a tabulated column.

DR-104 Depth of Cover Tables for Concrete and Corrugated Pipe.
When bidding unclassified pipe, specify pipe class for RCP since that is an option.

DR-121 Connected Pipe Joints.

Specify the type in the Remarks column on the pink sheet. All RCP pipe sections, excluding trenchless installations, will have these connectors.

DR-122 Type “C” Connectors.

When extending a pipe with a pipe and the slope of the extension is different from the slope of existing pipe, a type C-1 connection will be required.

When extending an existing RCB with a pipe, normally remove the headwall to the front face of the parapet and UAC the parapet, and use a C-2 collar. If the parapet is skewed to the barrel, Type “D” pipe sections (DR-141) may be specified to match the skewed headwall or in rare occasions the RCB may be cut 90 degrees to the barrel behind the parapet. Keep in mind to try to line up the inlet and especially the outlet to the draw. Specify type and quantity in the Remarks on the pink sheet.

DR-141 Pipe Bends (Elbows and D Sections).

See the notes on DR-141 for the limitations and construction of bends for “D” sections and elbows. For “D” Sections greater than 10 degrees consider using elbows. A standard Type “D” section is 7.5 degrees.

DR-142 Culvert Pipe Tee Sections.

Specify quantity, culvert type, size and angle in the Remarks on the pink sheet. The concrete pipe cap is useful when staging construction to keep siltation out of the pipe.

DR-205 Concrete Apron With End Wall andDR-206 Low Clearance Concrete Pipe Apron With End Wall.

May be used when inlet elevation must be lowered due to limited fill height. Specify Top Elevation in the Remarks on the pink sheet.

DR-212 Beveled Pipe and Guard.

When designing a median ditch near a crossover, it is preferred to outlet the median drainage to an outside, upstream ditch except when outletting along the flood plain of a stream. In those instances, the median pipe should drain to the downstream side of the stream. However, when entrances on both sides of the crossover restrict the outlet of the median pipe, DR-212 will allow the drainage to continue down the median

DR-213 Pipe Apron Guards.

The guard is to be used where the concrete inlet apron opening is within the Clear Zone. Due to possible clogging, try to avoid guards at the outlet apron. Specify quantity in the Remarks on the pink sheet.

DR-501 Corrugated Metal Type “A” Diaphragm.

Specify quantity in the Remarks on the pink sheet.

EC-301 Rock Erosion Control (REC).

Splash basins will be placed at the outlet of all cross road pipes including extensions to mitigate erosion. Median pipes will be assessed as to the need for splash basins based on the ditch grade.

SW-562 Standard Road Plan Vertical Throat Area Intake.

This intake has large openings allowing for minimal head water and is acceptable in the clear zone. This standard intake is the most hydraulically efficient for conveying flows.

DR-601 Reinforced Concrete Pipe Culvert.

This is used for concrete pipes under pavements. For non-NHS routes and where the ADT is less than or equal to 3000 VPD, DR-651 should be used for culverts under the highway. DR-651 for Unclassified Pipe Culvert should be used for all entrances and driveways and for unpaved side roads if it is not replacing an existing concrete pipe. Unless noted all pipes will have aprons.

DR-602 Reinforced Concrete Pipe Culvert with Tees.
Teed pipes are generally not recommended except in a side ditch outside the clear zone. See DR-142 for description of tee. Specify the tee G dimensions, quantity, size and angle in the Remarks on the pink sheet. See DR-612 for location of tee aprons.

DR-611 Reinforced Concrete Pipe Culvert Letdown Structure.
See DR-631 for a similar culvert as a side ditch letdown and DR-652 for an unclassified letdown. Specify length "F", desired elbow type (D Section or Elbow), elbow angles and quantity in the Remarks on the pink sheet.

DR-612 Apron Tee Inlet.
This is generally used in conjunction with DR-602. To be used as the inlet to a crossroad pipe when all the flow is coming down a steep side ditch (slope greater than approximately 4%). This inlet will prevent the side ditch water from bypassing the inlet and overtopping the adjacent ditch block and will allow the side ditch water to "turn the corner" within the pipe.
Specify the pipe cap, if needed DR-142 in the Remarks on the pink sheet.

DR-621 Pipe Extension.
This is commonly used to extend existing structures. All existing RCB or RCP shall be extended with a concrete pipe regardless of the ADT. Specify A and B in the Remarks on the pink sheet.

DR-622 Pipe Extension Horizontal Bend One or Both Ends.
This is commonly used to extend existing structures. All existing RCB or RCP shall be extended with a concrete pipe regardless of the ADT. Skew angle of extension is different than skew of pipe. The extension skew is referenced to the existing pipe, not the centerline of road, e.g., skew is 15 degrees Rt., not 15 degrees Rt. ahead. Specify in the Remarks on the pink sheet whether skew is the pipe skew or the extension skew.
If the extensions on both ends of an existing structure are skewed, specify in the Remarks how much each extension is skewed, e.g., "Right end or outlet is 15 degrees Rt., Left end or inlet is 20 degrees Rt." Specify the number of bends, culvert type, and degrees in the Remarks on the pink sheet.

DR-625 Pipe Extension Letdown Structure With Metal Apron.
Designer must select either CMP or PEP for the outlet portion of the pipe. Specify A, B, C, E, and L in the Remarks on the pink sheet.

DR-626 Pipe Extension-Adding Lanes.
See Guidelines at beginning of this section and DR-621.

DR-627 Pipe Extension Horizontal Bend-Adding Lanes.
See Guidelines at beginning of this section and DR-622.

DR-628 Pipe Extension Both Ends Horizontal Bends (Optional)-Adding Lanes.
See Guidelines at beginning of this section and DR-622.

DR-629 Pipe Extension Letdown Structure Horizontal Bend (Optional)-Adding Lanes.
See Guidelines at beginning of this section, DR-622 and DR-625.

DR-631 Corrugated Pipe Culvert Letdown Structure With Single Elbow and
DR-632 Corrugated Pipe Culvert Letdown Structure With Double Elbow.
Can be used for a side ditch letdown. Note that the Location point is at the inlet of the pipe, not at the centerline of dike or roadway.
Dike (see standard EW-110) over letdown should be Type F, with a 20 ft top width for structures 48 inch and larger. Maximum size is 60 inches to prevent uplift of the CMP inlet. For larger culverts consider using concrete pipe or box culverts. Outlet aprons are optional if outlet is next to an RCB. Minimum cover over length "C" is 1 ft. Specify A, B, C, L, and quantity of diaphragms in the Remarks on the pink sheet.

DR-641 Concrete/Corrugated Pipe Culvert letdown Structure With Metal Apron.
Designer must select either CMP or PEP for the outlet portion of the pipe.

DR-642 Apron Pipe Tee Inlet.
Note that the location point is at the inlet. This culvert is generally used in a side ditch. If CMP is used, specify the quantity of type “A” diaphragms in the Remarks on the pink sheet. Teed pipes are generally not recommended except in a side ditch outside the clear zone.

DR-651 Unclassified Pipe Culvert.
Unclassified pipes are often used under unpaved side roads and entrances. This OD SRP is also used for Unclassified Roadway pipes where the ADT < 3000 VPD and the location is a non-NHS route.

DR-652 Unclassified Letdown Structure Single Elbow.
Use when an elbow under the road is needed. Unclassified pipes are often used under unpaved side roads and entrances. Type “A” diaphragms are not required when DR-652 is used under a roadway since “piping” is much less likely due to the length of pipe under fill and possible better compaction of bedding and backfill.

DR-653 Unclassified Roadway Letdown Pipe With Metal Apron.

ROAD DESIGN DETAIL 4311.
Details of Barnroof Foreslope at Drainage Structure. Typical 4311 is used for culvert spot replacements or extensions as the site grading to be shown on the plan view of the TS&L.

ROAD DESIGN DETAIL 4315 and 4316.
When possible it is preferred to remove an existing structures rather than plug and abandon.
When jacking pipes to replace existing structures, use RDD 4315 and 4316 to abandon with flowable mortar.
When using RDD 4315 and 4316 for Stock Passes that also convey drainage, it is preferred using an RCP rather than a flexible pipe to prevent the pipe floating while pouring the flowable mortar.

C4.3 Culvert Plan Preparation

C4.3.1 Pink Sheets

C4.3.2 Pipe Sizes

C4.3.3 Culvert Type

C4.3.4 Horizontal Alignment

C4.3.5 Vertical Alignment

C4.3.6 Length Determination

Determining Culvert Lengths

Required Length
The required length of a culvert is generally determined by one of two methods:

1. by the clear zone; or,
2. by fitting the culvert to the typical cross section, such as the barnroof.

Both methods must be checked and then compared; the **greater** of the two distances is the required culvert length.

The first method should meet the preferred clear zone table in [OD DM 8A-2]. Culvert locations where ROW, environmental or other economic impacts could occur, the clear zone may be designed to meet the acceptable clear zone with approval from the supervising Section Leader. This clear zone is measured from the edge of the driving lane to the back of the RCB parapet or the top opening of the pipe apron. (Note that the clear zone is measured from the edge of the driving lane [typically 12 ft], not from the edge of any additional pavement that will be used as part of the shoulder.) Only in rare circumstances shall any replacement or extended culvert be shorter than required by Table 3.1. (One exception is the inlet end of a median drain with an apron guard.)

The second method computes the culvert length by fitting the culvert to the roadway barnroof section. In other words, the computed length is determined by intersecting the barnroof with the back of the RCB parapet or the top opening of the pipe apron. See "Determining Culvert Lengths Using the Computations Section on Pink Sheets" in this appendix for this method. This is the primary purpose of the Computations Section on the pink sheets.

To repeat the statement above, the **greater** of the two distances from these methods is the required culvert length.

Computations Section on Pink Sheet
The Computations section on the pink sheet should be used to determine the lengths of pipe and box culverts. The terms from the pink sheet are defined below to aid in the calculation of lengths based on the typical cross section (e.g., barnroof section) for a given project. The calculated length must be compared to the minimum length required by clear zone criteria. The greater of the two lengths will govern. See comments on line 12.

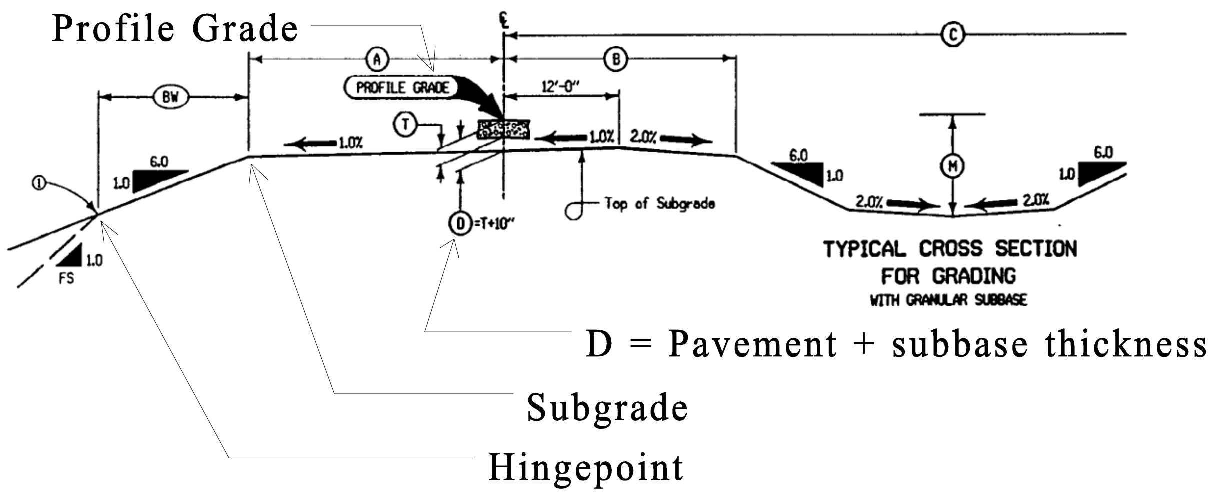
1. **Profile Grade -** Grade at a pre-determined station. Taken from the Road Plan and Profile sheet. If the structure is skewed, the Grade Rt and Lt could vary. Use the grade at the station where the parapet or top of pipe opening is perpendicular to road centerline.

2. **Vertical Drop (Subgrade or Hinge Point) -** Vertical distance down from Profile Grade to Subgrade Point to Hinge Point. For any given project, the Vertical Drop generally stays constant except in areas with superelevations. See the following drawing that depicts the Vertical Drop and the Working Point Elevation.

3. **Working Point Elevation -** Line 1 minus Line 2.
Either the subgrade elevation or the hingepoint elevation is used as the Working Point Elevation. See the typical grading section below. Which point to use in the computation of culvert length depends on the elevation of the top of the culvert. If the top of the pipe opening (or RCB parapet) is above the hingepoint elevation, then the subgrade is used as the working point. If the top of the pipe opening (or RCB parapet) is below the hingepoint elevation, then the hingepoint is used as the working point.

    Subgrade Elevation
    Profile grade elevation
    -Pavement and subbase thickness
    -Subgrade cross slope times distance (typically 1% X "A")
    = Subgrade elevation

Hingepoint Elevation
Subgrade elevation
-"BW" / 6:1 slope
= Hingepoint elevation



4. **Flowline -** This is the actual proposed culvert flowline elevation, not the ground elevation.

5. **Difference** - Line 3 minus line 4 = vertical difference between the Working Point Elevation and the culvert Flowline Elevation.

6. **(D+T) or (H+Hdwl)**

   D + T (for pipes only) = Diameter of pipe + the thickness of pipe (see RF-1).

   H + HDWL (for RCBs only) = Nominal height of the box (e.g., 8 feet) + the height of parapet (2 feet) and frost trough (4 inches).

7. **Difference - ** Height Difference (line 5) minus D+T or H+HDWL (line 6). Gives the actual vertical distance between the top of structure to soil at the working point (hinge point or subgrade).

8. **Slope -** Embankment Slope from the working point (subgrade or hinge point) to the top of pipe opening or parapet. The slope is generally 6:1 when using the subgrade as the working point or 3.5:1 when using the hingepoint.

9. **Working Point (Subgrade or Hinge Point) to End of Foreslope** - Line 7 multiplied by line 8 = the horizontal distance from the working point to the top of the pipe opening (or the RCB parapet).

10. **Distance = Centerline to Working Point -** On 2-lane roadways, this is the horizontal distance from the centerline of roadway to the working point (Subgrade or Hingepoint).

    On 4-lane roadways, this is the horizontal distance from the construction centerline (typically the median) to the working point (Subgrade or Hingepoint).

11. **(1.5:1) or (Dimen. B) for pipes only -** Line 9 determines the culvert length only to the top of the pipe, so the distance from the top of the pipe to the end of the apron must be accounted for. For

1200mm or smaller pipes, use the “B” dimension of the pipe (see Road Standards); for 1350mm or greater pipes, use 1.5 x D. For box culverts, Line 11 is zero.

12. **Length -** This is the total calculated length of the culvert from the roadway centerline to either the end of the pipe or the back of RCB parapet. This is the sum of lines 9, 10 and 11. Then compare this calculated length to the minimum length to be sure it meets the minimum clear distance as follows:

    For RCBs, minimum length = Lane width + Clear zone
    For pipes, minimum length = Lane width + Clear zone + Apron “B” dimension

    Select the greater of calculated length or minimum length.

13. **Secant of Skew Angle -** If structure is skewed, list the secant of the angle the structure is to centerline of roadway.

14. **Length on Skew -** Line 12 times line 13 gives the actual length along the centerline of the culvert.

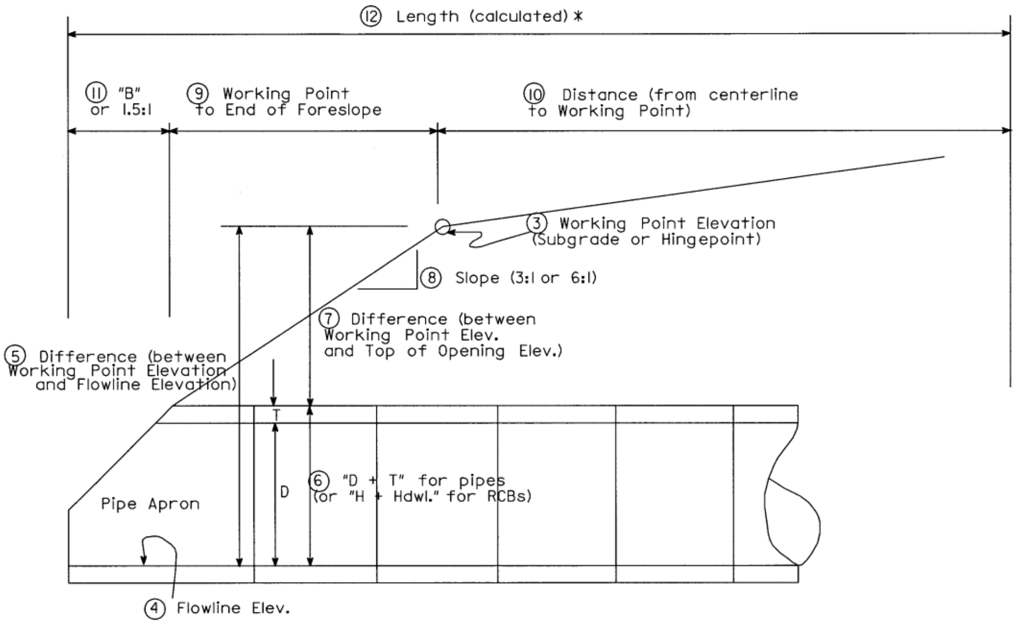
15. **Add for Hdwl Skew -** The length (line 12 or 14) of the structure is calculated along the centerline of the culvert. However, if the parapet of the headwall is not parallel to the roadway (e.g., a 0 degree skewed headwall with a 10 degree skewed barrel), then one corner of the headwall will fall closer to the roadway than the centerline of the culvert. This corner must be extended to equal the length that was calculated on the centerline (line 12 or 14). This situation will also pertain to all pipes; a length must be added to get the end of the apron beyond this point.

16. **Length -** Add “Length on Skew” (line 14) and “Add for Hdwl Skew” (line 15).

17. **Length Present Structure -** If designing an extension, determine the length of the existing structure from the road centerline to the front (not the back) of the RCB parapet or to the first pipe barrel section.

18. **Extension -** Length (line 16) minus Length Present Structure (line 17). This gives the extension length needed.

Pink Sheet----Computations Section



* Compare calculated length to the "clear zone" minimum length. Use the greater length.

Sample Pink Sheet

Form 621001
3-93

Iowa Department of Transportation
Highway Division
Bridge Survey Record
FIELD NOTES FOR CULVERTS

Township 72N Range 11W Section 25 Civil Township Locust Grove

Station Present Structure or Stream — Station Proposed Culvert 344 + 70

Drainage Area in Acres 6 El. Hi. Water — Character Water Shed R

Upstream Land Use Cult. Anticipate Any Change? No

Bench Mark No. —

Type and Elev. of Low Upstream Buildings —

Present Structure: Type None Design No. ___ Br. Rdwy. ___

Spans ___ Ht. ___ Length: B. to B. Ppts. ___ Pipe ___ Flume ___

Elevation: Grade ___ Inlet ___ Outlet ___ Flume Outlet ___

Condition ___ Skew Angle ___

Proposed Culvert: Type 1501, RF-1 & CMP Fin. Rdwy. Width (Sh-Sh) 40'

Spans 24" Ht. — Length New Constr: ~~RCB~~ CMP 82' ~~Pipe~~ RF-1 60' + 1-RF-3 Aprons ~~Flume~~ 1-RF-5

Elevation: ~~Grade~~ Profile Grade 731.20 F.L. Lt. 701.0 F.L. Rt. 725.4 F.L. Other 721.5, 702.1

Ext. Lt. — Rt. — Total Length Lt. 126' Rt. 46' Skew Angle 0 ~~(Lt.) (Rt.)~~ Ahead

— Contr. Dike — Sta. — El. — Type — Road Contr. Ditch outlet

Design Q 18 C.F.S. Frequency 50 Yr. Design High Water Elev. 728.1 Depth 2.7 Ft.

Design Fill Height 5 Ft. Pipe Class 2000 D. Class Bedding C — ADT = — VPD

Disposition of Present Structure —

Remarks A = 76', B = 60', C = 2', E = 20', Q = 6.5'

Two – 16° CMP elbows, One RF-2 Type C-3 adapter

Computations

	Left		Right
1 Profile Grade Elev.	731.20	Profile Grade Elev.	731.20
2 Vert. Drop {Subgrade or Hinge Point	- 4.7	Vert. Drop {Subgrade or Hinge Point	- 1.9
3 Working Point Elev.	= 726.50	Working Point Elev.	= 729.3
4 Flow Line	- 701.0	Flow Line	- 725.4
5 Difference	= 25.50	Difference	= 3.9
6 (D + "T") or (H + Hdwl.)	- 2.3	(D + "T") or (H + Hdwl.)	- 2.3
7 Difference	= 23.2	Difference	= 1.6
8 Slope (6:1, 3:1, etc.)	× 3	Slope (6:1, 3:1, etc.)	× 6
9 Working Point to End of Foreslope	69.6	Working Point to End of Foreslope	9.6
10 Dist. = ℄ to Working Point	+ 48.0	Dist. = ℄ to Working Point	+ 28.0
11 (1½:1) or Dimen. "B" 12+30+3.6	+ 3.6	(1½:1) or Dimen. "B" 12+30+3.6 =	+ 3.6
12 Length, Calc. or Min (45.6)	121.2	Length, Calc. or Min () 45.6	~~41.2~~ 45.6 min.
13 Secant of Skew Angle	×	Secant of Skew Angle	×
14 Length on skew		Length on skew	
15 Add for hdwl. skew	+	Add for hdwl. skew	+
16 Length		Length	
17 Length pres. struct.	-	Length pres. struct.	-
18 Extension		Extension	

Sample Pink Sheet

Form 621001
3-93

Iowa Department of Transportation
Highway Division
Bridge Survey Record
FIELD NOTES FOR CULVERTS

Ramp "D"

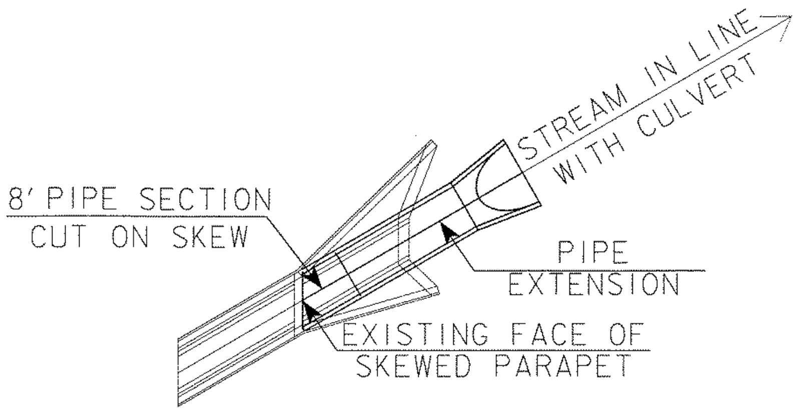
Township 72N Range 11W Section 29 Civil Township Locust Grove
Station Present Structure or Stream — Station Proposed Culvert 4527 + 56.00
Drainage Area in Acres 14 El. Hi. Water — Character Water Shed F
Upstream Land Use Cultivated Anticipate Any Change? No
Bench Mark No. —
Type and Elev. of Low Upstream Buildings —
Present Structure: Type None Design No. Br. Rdwy.
Spans Ht. Length: B. to B. Ppts. Pipe Flume
Elevation: Grade Inlet Outlet Flume Outlet
Condition Skew Angle
Proposed Culvert: Type 1201 RF-1 Fin. Rdwy. Width (Sh-Sh) 26'
Spans 24"Ø Ht. — Length New Constr: RCB — Pipe 94' + 2 Aprons Flume —
Elevation: Profile Grade 756.45 F.L. Lt. 748.4 F.L. Rt. 740.8 F.L. Other 741.1
Ext. Lt. — Rt. — Total Length Lt. 50' Rt. 56' Skew Angle 20° ~~(Lt.)~~ (Rt.) Ahead
Road Contr. Dike Lt. Sta. 4527+70 El. 751.3 Type M Contr. Ditch
Design Q 23 C.F.S. Frequency 50 Yr. Design High Water Elev. 751.8 Depth 3.4 Ft.
Design Fill Height 7 Ft. Pipe Class 2000 D. Class Bedding C — ADT = — VPD
Disposition of Present Structure —
Remarks F = 30' , 5° bend (RF-13)

Computations

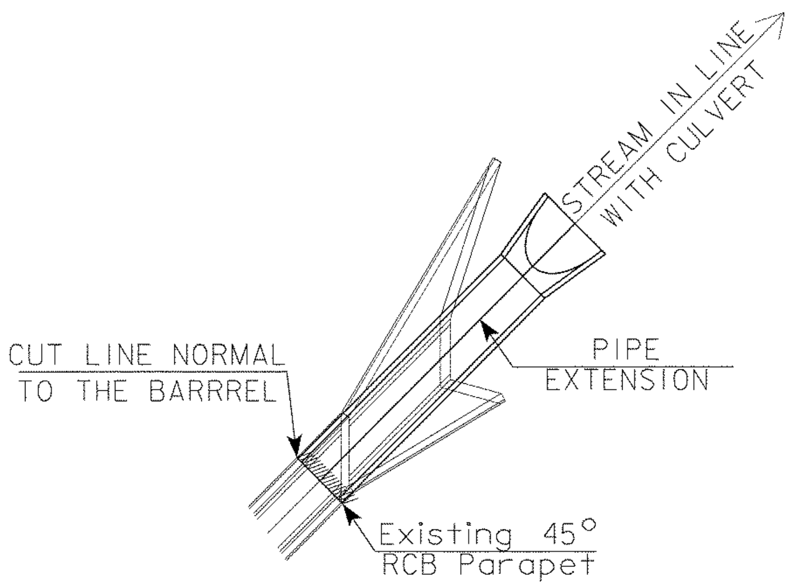
Left			Right	
(1) Profile Grade Elev. 4527+40	756.64		Profile Grade Elev. 4527+65	756.31
(2) Vert. Drop (Subgrade or Hinge Point)	- 5.0		Vert. Drop (Subgrade or Hinge Point)	- 5.0
(3) Working Point Elev.	= 751.64		Working Point Elev.	= 751.31
(4) Flow Line	- 748.4		Flow Line	- 740.8
(5) Difference	= 3.24		Difference	= 10.51
(6) (D + "T") or (H + Hdwl.)	- 2.3		(D + "T") or (H + Hdwl.)	- 2.3
(7) Difference	= 0.94		Difference	= 8.21
(8) Slope (6:1, 3:1, etc.)	× 3		Slope (6:1, 3:1, etc.)	× 3
(9) Working Point to End of Foreslope	2.8		Working Point to End of Foreslope	24.6
(10) Dist. = ℄ to Working Point	+ 40.0		Dist. = ℄ to Working Point	+ 24.0
(11) (1½:1) or (Dimen. "B")	+ 3.6		(1½:1) or (Dimen. "B")	+ 3.6
(12) Length, Calc. or Min (16+20+3.6= 39.6')	46.4		Length, Calc. or Min (20+3.6 23.6')	52.2
(13) Secant of Skew Angle 20°	× 1.06		Secant of Skew Angle 20°	× 1.06
(14) Length on skew	49.4		Length on skew	55.3
(15) Add for hdwl. skew	+ —		Add for hdwl. skew	+ —
(16) Length Use →	50'		Length Use →	56'
(17) Length pres. struct.	- —		Length pres. struct.	- —
(18) Extension	—		Extension	—

C4.4 Pipe Culverts

C4.4.1 Extensions



WHEN EXTENDING A 15° OR A 30° SKEWED RCB WITH ANY SIZE RCP, OR A 45° SKEWED RCB WITH A 48″ DIAMETER OR LESS RCP, REMOVE HEADWALL TO THE FACE OF THE PARAPET AND EXTEND WITH AN 8′ PIPE SECTION CUT TO THE SKEW ANGLE OF THE PARAPET.



WHEN EXTENDING A 45° SKEWED RCB WITH AT LEAST A 54″ DIAMETER RCP, CUT THE BARREL BEHIND THE PARAPET NORMAL TO THE BARREL.

C4.4.2 Median Pipes

C4.4.3 Ditch Letdowns

C4.4.4 Culvert Liners

C4.4.5 Culvert Maintenance

C4.4.6 Uplift of Culvert Inlets

C4.4.7 Trenchless Construction

C4.4.8 Slope Tapered Inlet for Pipes

January 11, 1999

Design Guidelines for Slope Tapered Pipe Culverts

The purpose of using slope tapered pipe culverts is to reduce construction costs and still provide the same hydraulic capacity and upstream headwater. The concept will be used primarily on DR-641 culverts which have concrete pipe on a relatively flat slope under the pavement and corrugated metal or polyethylene pipe down the steep foreslope of the highway embankment. The intent is to use available precast concrete pipe appurtenances and thus avoid special, costly designs by the manufacturers. This keeps the cost of material supply, and therefore total installation, lower. For example, by reducing a 48-inch pipe to a 36-inch pie, the cost savings for a 150-foot long culvert may be $25/foot X 150' = $3750. This savings should be compared to the costs of elbows and reducers to decide if a slope tapered inlet is practical at a given site.

The culvert site normally will meet two basic requirements to qualify for a tapered inlet. The first is that the additional costs for special pipe sections are offset by the reduction in construction costs. The second is that the site must have enough fall for the design to perform properly, typically at least four to six feet.

The culvert inlet is made large enough to keep the depth of water at the entrance within allowable limits. The slope taper section funnels the water down a steep slope and the barrel diameter decreases. The barrel section is designed to flow nearly full when carrying the design discharge. Frequently the outlet will have a letdown pipe or flume.

Design Steps

There are five basic steps for the hydraulic design a pipe culvert with a slope tapered inlet.

1. Determine the design discharge. The Iowa Runoff Chart shall be used for rural watersheds draining 1280 acres or less.
2. Determine the allowable depth of water at the inlet. Typically, culverts should be designed to have one foot to two feet of water above the top of the inlet.
3. Select an inlet size that results in a flow depth less than or equal to the allowable. Inlet control nomographs from FHWA's "Hydraulic Design of Highway Culverts" (HDS No. 5) can be used for this.
4. Select a barrel size and slope that results in the barrel flowing less than full. Select a slope steep enough to maintain supercritical flow. Charts in FHWA's "Design Charts for Open-Channel Flow" (HDS No. 3) have been developed from Manning's equation and can be used to select the appropriate slope.
5. Determine the drop needed for the slope section. The minimum drop needed is the specific energy at the inlet (H_1) minus the specific energy at the barrel (H_2) plus energy losses (H_L). Specific energy is the depth plus velocity head at a given location. The hydraulic principles for round pipe are the same as described in the section for slope tapered box culverts. Although the appearance of the Design Graph for pipe culverts is different, the calculations are similar.

The following guidelines, chart and worksheet are provided to assist in the hydraulic design.

When the inlet will be raised significantly to create a pond, geotechnical concerns must be considered to ensure that seepage through the embankment is not excessive.

Guidelines

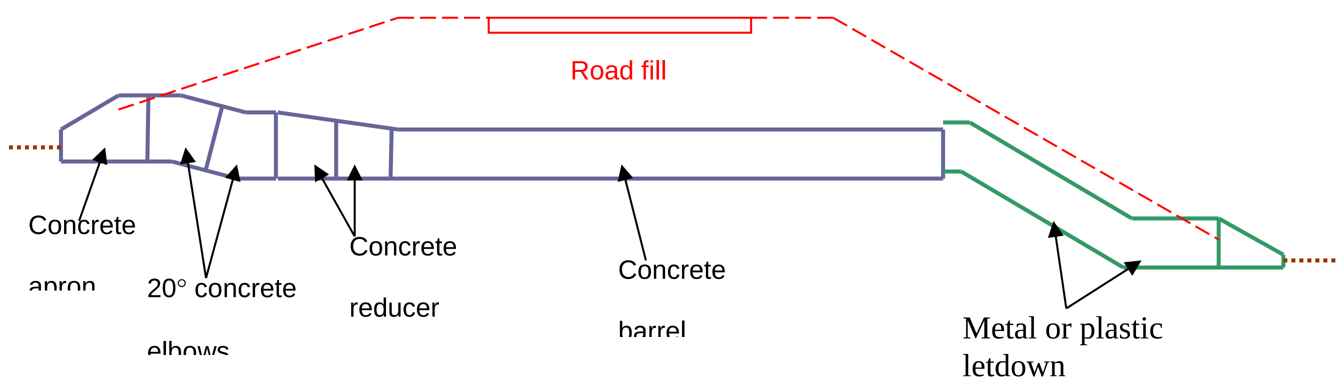
Some of the following guidelines were verified by the hydraulic research in 1997 at FHWA's Turner-Fairbanks Highway Research Center in Virginia:

1. Use only the reductions in diameter listed in the table. Any variations to this table should be verified with detailed hydraulic calculations.
2. In order to maintain supercritical velocities in the concrete barrel, use the minimum slope or steeper as shown in the table. This assumes a depth of flow of 0.8 x D and an "n-value" of 0.012. If the discharge, slope or desired depth of flow vary from these assumptions, use FHWA's "Design Charts for Open-Channel Flow", HDS No. 3, to determine the minimum slope.
3. Concrete pipe reducers are available in four-foot long sections with six inches of diameter reduction per section. For example, if reducing pipe diameter by 12 inches two reducer sections are needed, resulting in an eight foot length of pipe.
4. For simplicity, design both concrete elbows at 20° each.
5. The 20° elbows end-to-end will give a vertical drop (Z) of approximately 2.1 feet. If greater drop is needed as determined in the design calculations, a four-foot long section of standard pipe could be installed between the two elbows. This results in a drop of approximately 3.5 feet.
6. Pipe outlets larger than a 48-inch diameter will generally need a cast-in-place reinforced concrete flume rather than a metal or polyethylene letdown pipe.

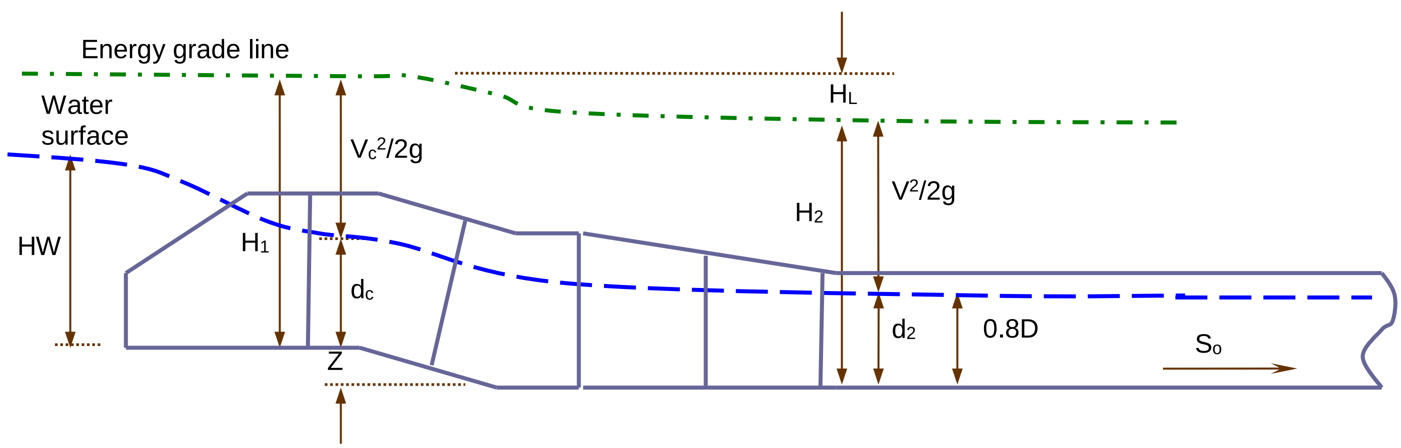
	Diameter Reduction, inches			
Approx. Q, ft^3/sec	**From**	**To**	**Vertical Drop (Z), feet**	**Minimum Barrel Slope, %**
350	84	72	2.1	0.8
350	84	66	2.1	1.1
295	78	66	2.1	1.0
295	78	60	3.5	1.3
245	72	60	2.1	1.0
245	72	54	3.5	1.6
200	66	54	2.1	1.2
200	66	48	3.5	2.0
160	60	54	2.1	0.9
160	60	48	2.1	1.5
125	54	48	2.1	1.0
125	54	42	2.1	1.7
96	48	42	2.1	1.2
96	48	36	2.1	2.0
71	42	36	2.1	1.3
50	36	30	2.1	1.6
33	30	24	2.1	2.0

Slope Tapered Pipe Culverts

Modified Type 1501 Letdown

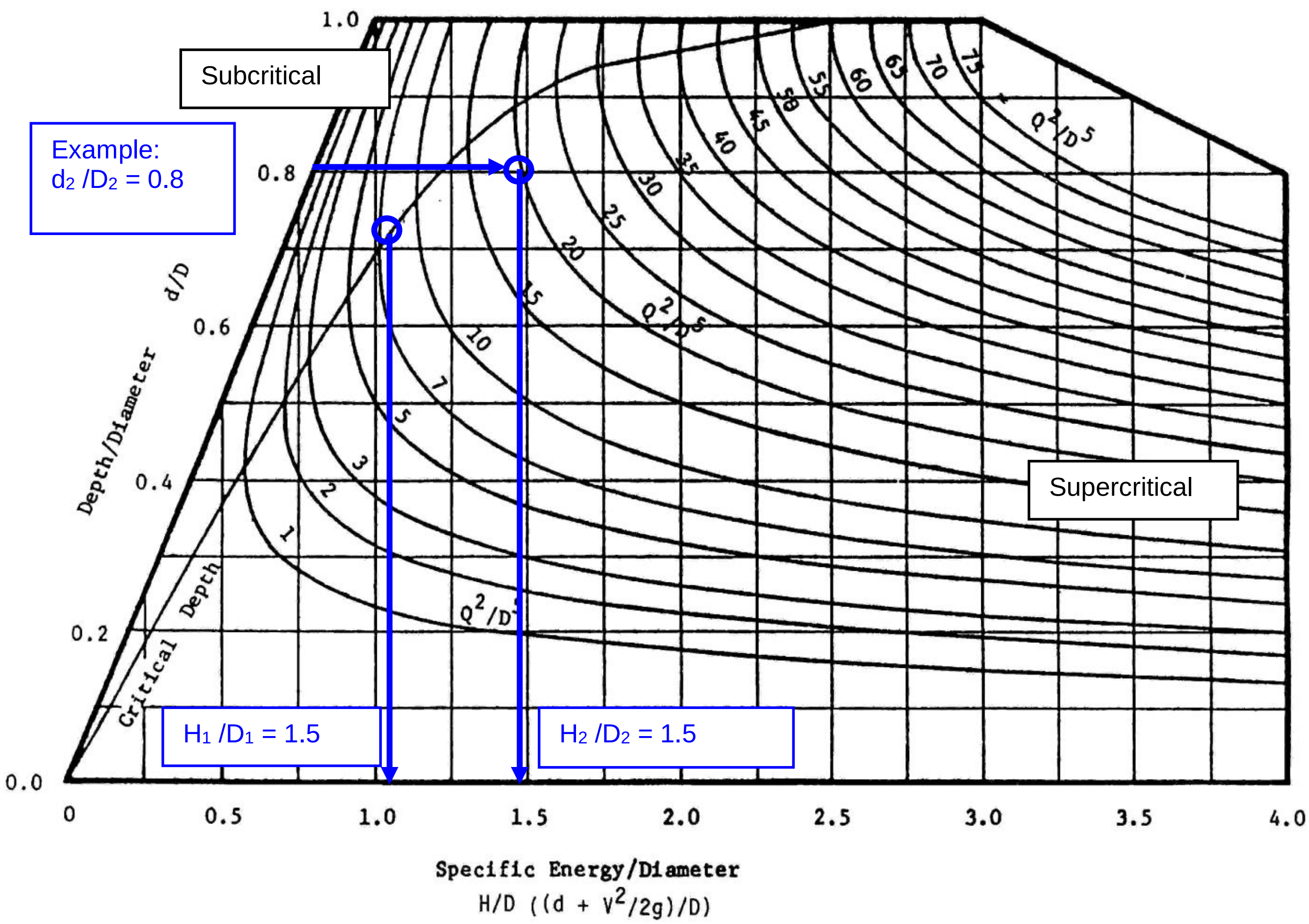


Hydraulic Performance



Design Graph for Slope Tapered Pipe Culverts

Specific Energy Curves for Circular Pipe



May 2, 1997

Worksheet for Slope Tapered Pipe Culverts

Project____________________County_______________Sta._______________

Designer_________________Date___________________

Variable	**Example**	**Trial 1**	**Trial 2**	**Trial 3**
Design Q , ft^3/s	250			
Inlet Section				
D_1 , ft (size of inlet)	6.0			
HW, ft (HDS #5)	7.1			
Q_1^2 / D_1^5	8.0			
d_c / D_1 (from Chart)	0.72			
H_1 / D_1 (from Chart)	1.05			
d_c , ft	4.3			
H_1 , ft	6.3			
Barrel Section				
D_2, ft (size of barrel)	5.0			
Q^2 / D_2^5	20.0			
d_n/D_2 = 0.8 (Design max. depth)	0.8	0.8	0.8	0.8
H_2 / D_2 (from chart)	1.50			
H_2 , ft	7.5			
Slope Tapered Section				
H_L, ft (assumed)	0.2	0.2	0.2	0.2
Z, ft (= $H_2 - H_1 + H_L$)	1.4			
Selected Z , ft	2.0			
Barrel Slope				
d_n , ft (= 0.8 X D_2)	4.5			
Min. Barrel Slope, % (table)	1.1			
Is the design acceptable?	Yes			

C4.4.9 Revetment for Pipes

C4.5 Reinforced Concrete Boxes (RCB's) and Designs

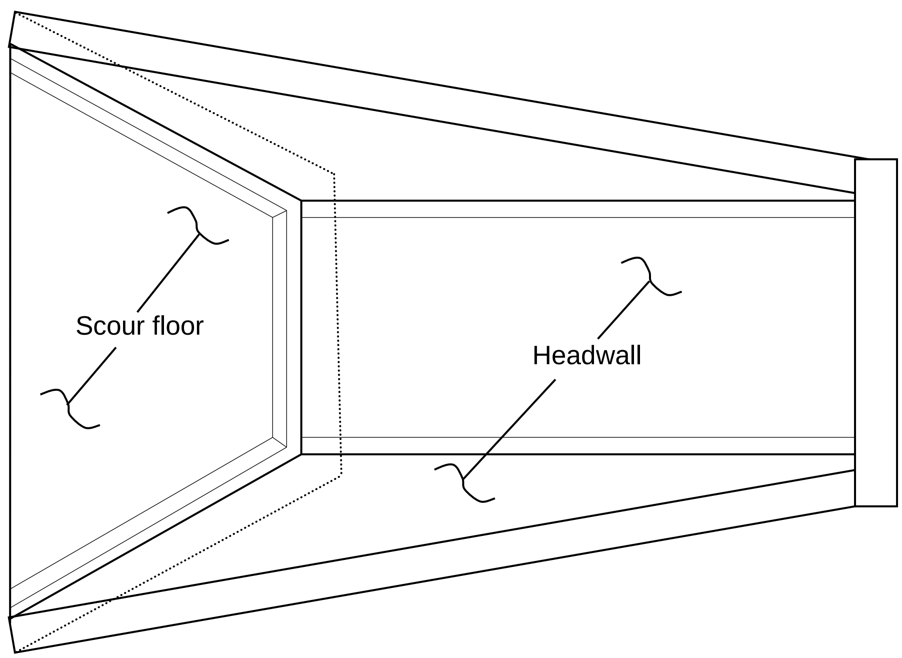
C4.5.1 Cast in Place RCB Standard Sizes

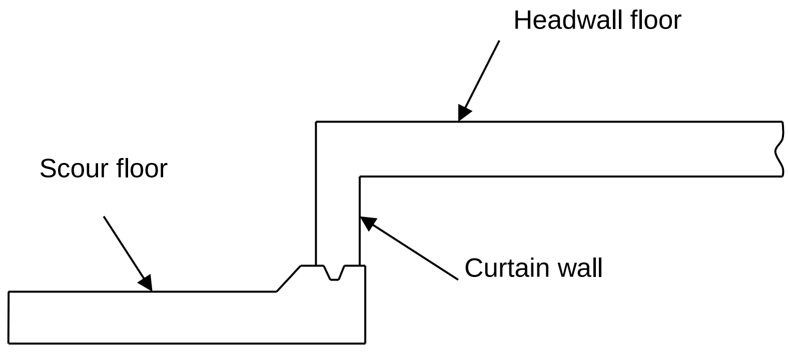
C4.5.2 Precast RCB's

C4.5.3 RCB Extensions

C4.5.4 Flumes and Scour Floors

Typical Scour Floor





Section through scour floor

C4.5.5 Drop Inlets

Design Guidelines for Drop Inlet Culverts

Drop inlets for pipe and box culverts can be beneficial solutions to some drainage and erosion problems. Hydraulically, they are useful when a culvert has limited available head upstream. Also, they can be used to raise the flowline to create a pond or stop channel erosion upstream.

When evaluating the hydraulics of drop inlet culverts, two controls must be checked to determine the design high water of the culvert. The first is barrel control using the orifice equation, also known as the full-flow equation, taken from a U.S. Soil Conservation Service technical memorandum for drop inlets. The equation is similar to the outlet control equation in FHWA's "Hydraulic Design of Highway Culverts", HDS No. 5. The second is weir control, using the broad-crested weir equation. The equation giving the highest water elevation is considered the controlling headwater.

A trial and error solution is needed to determine what size of barrel and weir are needed. Start by sizing the barrel and analyzing the hydraulics. When an acceptable size and headwater are obtained, assume a drop inlet opening of 1.5 to 2.0 times the barrel opening. Then calculate the head created by the weir and determine if a different size inlet is needed.

Worksheets are attached to aid in the calculations.

Barrel (Full Flow) Equation

$$Q = A\left[\frac{2\,g\,H}{1 + K_e + K_b + K_f \quad L_b}\right]^{0.5}$$

where Q = discharge, ft^3/sec

A = area of culvert barrel, ft^2

g = acceleration due to gravity = 32.2 ft/sec^2

H = head (energy) needed to pass the flow through the barrel, feet

K_e = entrance loss coefficient

K_b = bend loss coefficient

L_b = length of barrel, ft

K_f = friction loss coefficient = 29.16 n^2 / R$^{1.33}$

n = roughness coefficient

R = hydraulic radius of barrel = area / wetted perimeter, ft

Assume K_e + K_b = 1.0 for typical Iowa DOT drop inlet

n = 0.012 for smooth pipe, or 0.024 for corrugated metal

R = A/2(W + H) for RCBs or D/4 for round pipe barrels

h_o = height of hydraulic grade line at outlet = TW or (d_c + D)/2, whichever is greater, ft

(TW can be determined from Manning's equation using a downstream valley section. d_c can be found in Chart 4 or 14 in FHWA's HDS No. 5. D is the height of the barrel.)

This results in the following full flow equation, assuming a smooth (e.g., concrete) barrel:

$$Q = A\left[\frac{64.4\,H}{2 + 0.0042\,\frac{L_b}{R^{1.33}}}\right]^{0.5}$$

Or solving for H,

$$H = \left[\frac{0.1246\ Q}{A}\right]^{2}\left[\ 2\ +\ \frac{0.0042\ L_b}{R^{1.33}}\right]$$

H is the head (energy loss) required to pass the flow through the barrel. To determine the headwater (HW) elevation at the inlet, add H and h_o to the outlet flowline elevation, where h_o is either tailwater (TW) depth or $(d_c + D)/2$, whichever is greater. (See Chapter III of FHWA's "Hydraulic Design of Highway Culverts", HDS No. 5, for a more detailed discussion of barrel [outlet] control.)

Then compare HW elevation to allowable head water (AHW) elevation. If HW > AHW, a larger barrel is needed. If HW < AHW, either try a smaller barrel size or proceed with the weir control calculations as described below.

Weir Equation

$$Q = C\ L_w\ H^{1.5}$$

where Q = discharge, ft^3/sec

C = coefficient. Use C = 3.09

L_W = effective length of weir, feet. The typical IDOT drop inlet has a parapet on one side, so consider only three sides to determine L_w. (The parapet improves the inlet efficiency by minimizing vortex action.)

H = head, feet

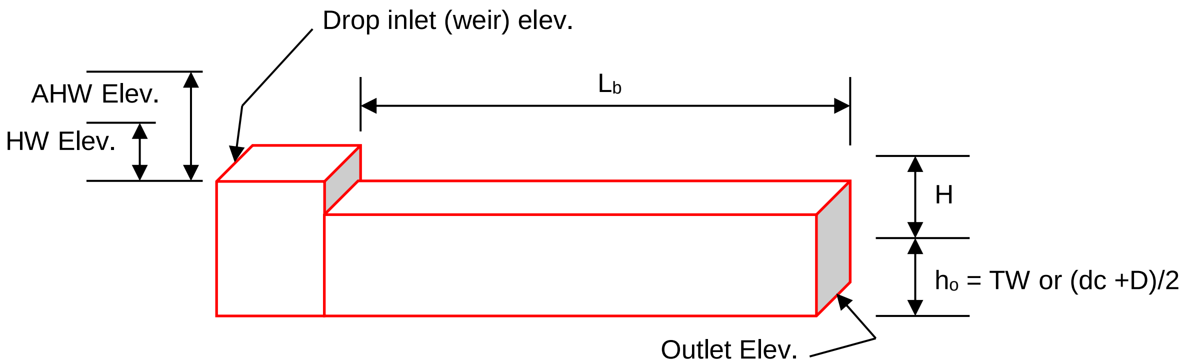
(H actually is depth plus velocity head, but for simplicity assume velocity head as negligible. This will result in a conservative headwater design.)

Or solving for H,

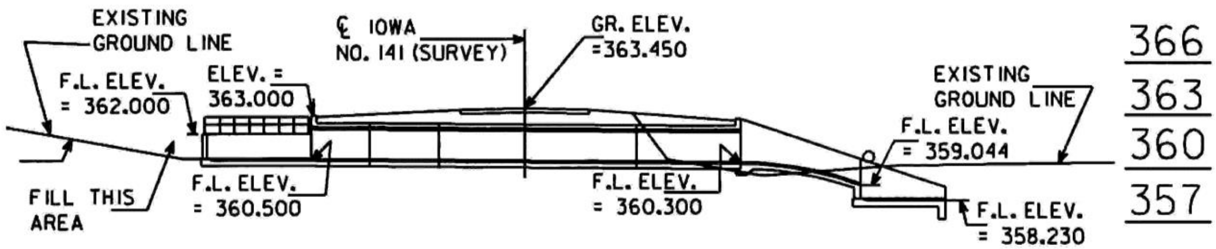
$$H = \left[\frac{Q}{C\ L}\right]^{0.667}$$ (Equation 3)

H is the head above the drop inlet flowline. To determine HW elevation for weir control, add H to the weir elevation and compare to the AHW elevation. If HW > AHW, then a larger weir is needed. If HW < AHW, either try a smaller weir or proceed with the selected size.

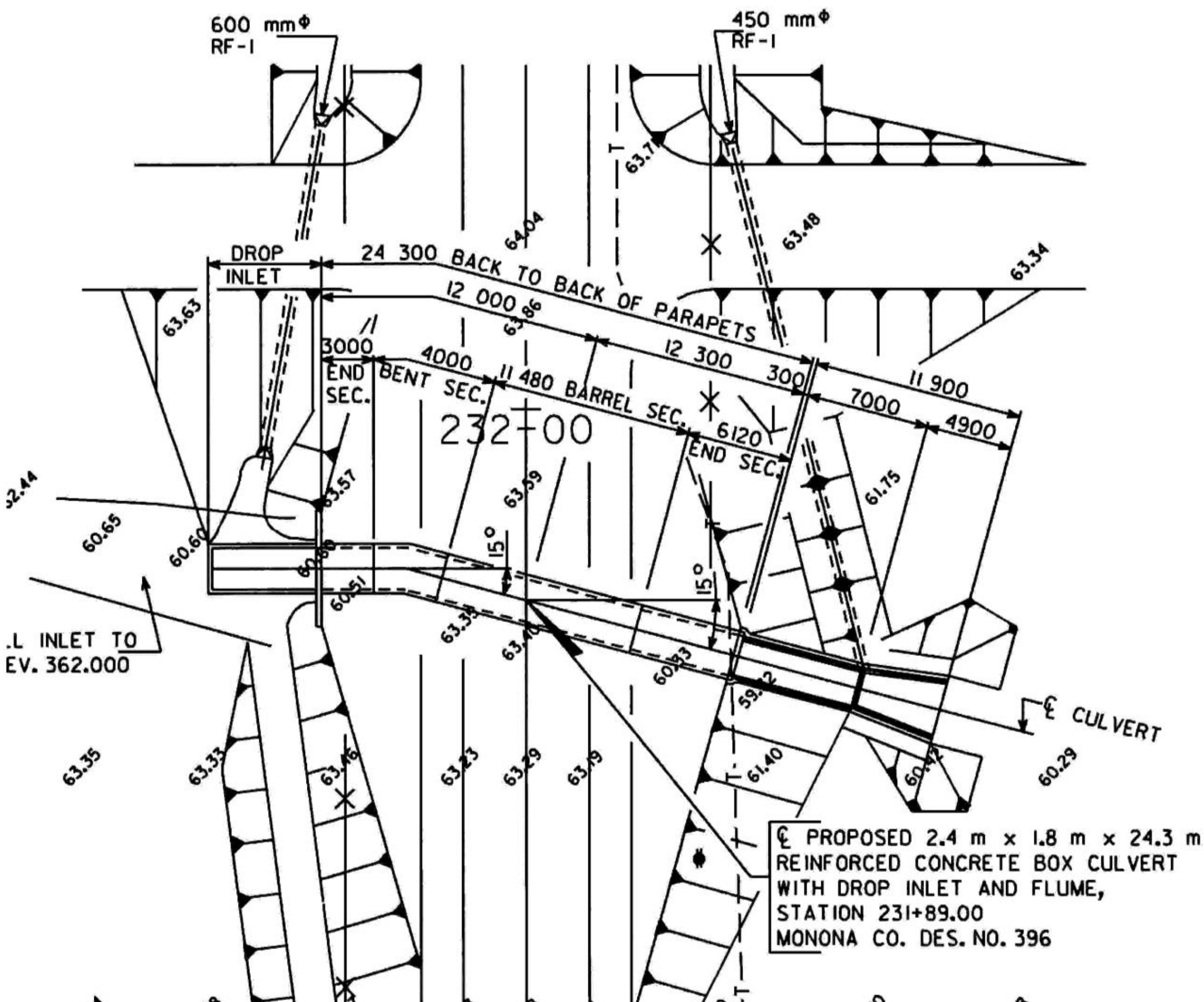
After an acceptable weir size is selected, compare HW for weir control to HW for barrel control. In essence, this comparison finds out which portion of the culvert is the most hydraulically restrictive: the weir or the barrel. The higher HW is the controlling elevation and indicates how high the water will get upstream of the culvert during the design flood.



Sample Drop Inlet Culvert

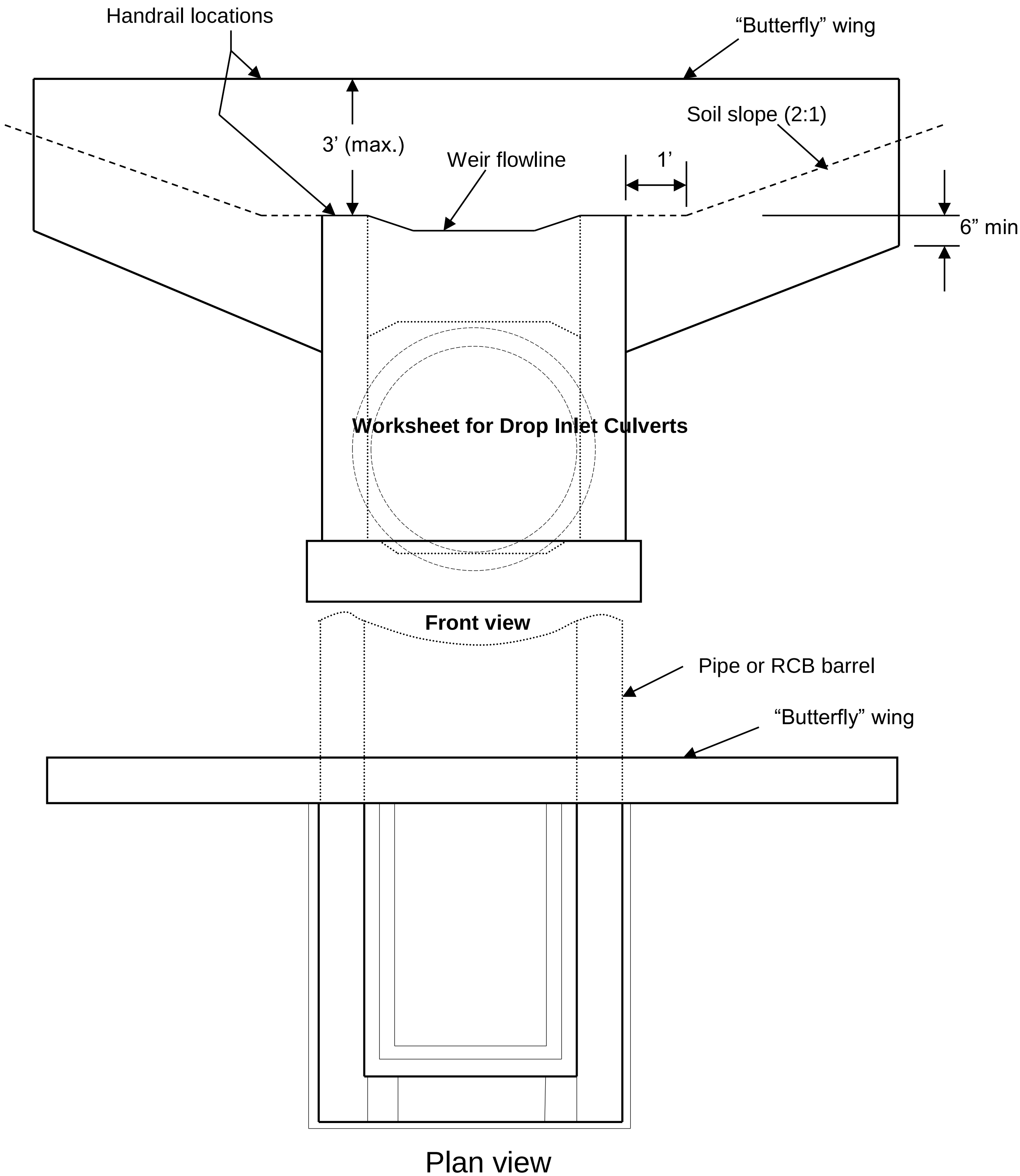


LONGITUDINAL SECTION ALONG ℄ CULVERT



SITUATION PLAN

Typical Drop Inlet Detail



Project____________________County_______________Des. No._______________

Sta.______________Designer____________Date___________________

	Example	Trial 1	Trial 2	Trial 3	Trial 4
Design Q, ft^3/sec	150				
Allowable HW Elev. (AHW)	108.0				
Barrel Design					
Barrel Size, ft X ft	4 X 4				
A, ft^2	16				
WP, ft	16				
R, ft (= A/WP)	1.0				
L_b, ft	80				
H, ft (Eqn. 1)	3.2				
$(d_c + D)/2$, feet	3.7				
TW, feet	4.0				
h_o, ft (= greater of TW or $(d_c + D)/2$)	4.0				
Barrel Outlet Elev.	100.0				
HW Elev. (=H + h_o + outlet elev.)	107.2				
Acceptable? If no, try a different barrel size.	Yes. HW < AHW.				
Weir Design					
Weir Size, ft X ft	4 X 8				
C	3.09	3.09	3.09	3.09	3.09
L_w, ft	20				
H, ft (Eqn. 3)	1.8				
Weir Elev.	106.0				
HW Elev.	107.8				
Controlling HW Elev.	107.8				
Acceptable? If no, try a different size.	Yes. HW < AHW.				

C4.5.6 Slope Tapered Inlets for RCB's

Design Guidelines for Slope Tapered Box Culverts

The purpose of slope tapered box culverts is to reduce construction costs by using a smaller barrel but still providing acceptable hydraulic capacity and upstream headwater. These special inlets have been used in Iowa and across the country since the 1950's or earlier. The design of these inlets includes rigid hydraulic design and good construction practice.

The culvert site normally will meet two basic requirements to qualify for a tapered inlet. The first is that the additional design costs are offset by the reduction in construction costs. The second is that the site must have enough fall for the design to perform properly, typically at least six to eight feet.

The culvert inlet is made large enough to keep the depth of water at the entrance within allowable limits. The slope taper section "funnels" the water down a steep slope as the culvert width decreases. The barrel section is designed to flow nearly full when carrying the design discharge. Generally the outlet has a flume and basin for energy dissipation.

Design Steps

There are five basic steps for the hydraulic design a box culvert with a slope tapered inlet.

1. Determine the design discharge. The Iowa Runoff Chart shall be used for rural watersheds draining 1280 acres or less.
2. Determine the allowable depth of water at the inlet. Typically, culverts should be designed to have one foot to two feet of water above the top of the inlet.
3. Select an inlet size that results in a flow depth less than or equal to the allowable. Inlet control nomographs from FHWA's "Hydraulic Design of Highway Culverts", HDS No. 5, can be used for this.
4. Select a barrel size and slope that results in the barrel flowing less than full. The barrel height should be the same as the inlet, while the barrel width should generally be no less than 50 to 60% of the inlet width. Select a slope steep enough to maintain supercritical flow. Charts in FHWA's "Design Charts for Open-Channel Flow", HDS No. 3, have been developed from Manning's equation and can be used to select the appropriate slope.
5. Determine the drop and length of the slope tapered section. The minimum drop needed is the specific energy at the inlet (H_1) minus the specific energy at the barrel (H_2) plus energy losses (H_L). Specific energy is the depth plus velocity head at a given location.

The following guidelines, charts and worksheets are provided to assist in the hydraulic design.

When the inlet will be raised significantly to create a pond, geotechnical concerns must be considered to ensure that seepage through the embankment is not excessive.

General Guidelines

1. HW from inlet control charts for proposed inlet size, no greater than D + 2 ft.
2. The height (D) of the structure does not change.
3. Calculated Z may be rounded to the next higher increment as described below.
   Minimum Z = 3 ft.
4. Taper can be designed by using the RCB standard reinforced steel pattern of inlet size for the entire length of the taper and varying the length of the transverse steel.
5. The barrel outlet flowline is usually set at least ½ (D) above streambed. This prevents the barrel from "drowning out".
6. The outlet usually has a flume with a basin that is buried 4 ft. to 6 ft. below streambed, to help dissipate energy.
7. The barrel slope (S_o) should generally be 1.5% or steeper in order to maintain supercritical flow and the maximum flow depth of 0.9D in the barrel. (See "Design Charts for Open Channel flow", HDS No. 3, FHWA, to determine specific flow depths for various slopes.)

8. An attempt should be made to design barrel sizes to conform with standard RCB sizes. This may mean starting with a "wide" non-standard inlet.
9. Assume energy loss, H_L = 0.2 ft. for all cases.

Guidelines for single RCBs

1. Use drop rate (L/Z) of approximately 3:1.
2. Ratio of barrel width to inlet width (B_2/B_1) should be 50% or greater.
3. For Z=3 ft., use L=10 ft. For Z=4 ft., use L=12 ft. For Z=5 ft., use L=15 ft.

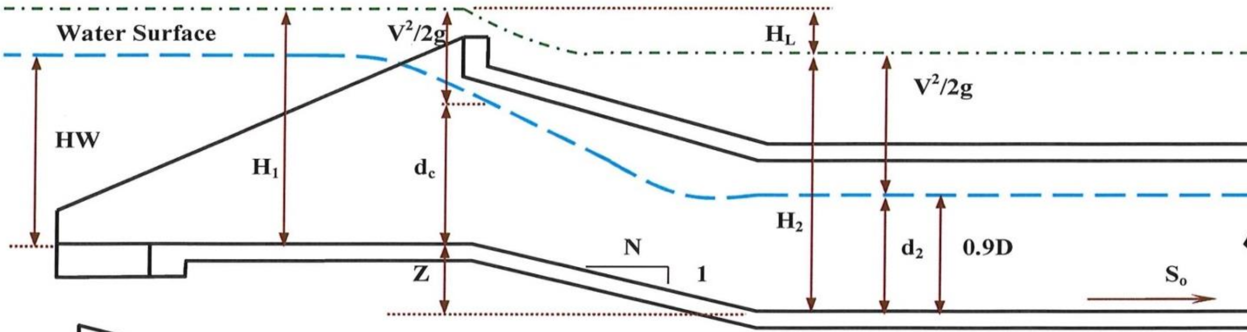
Guidelines for Twin RCBs

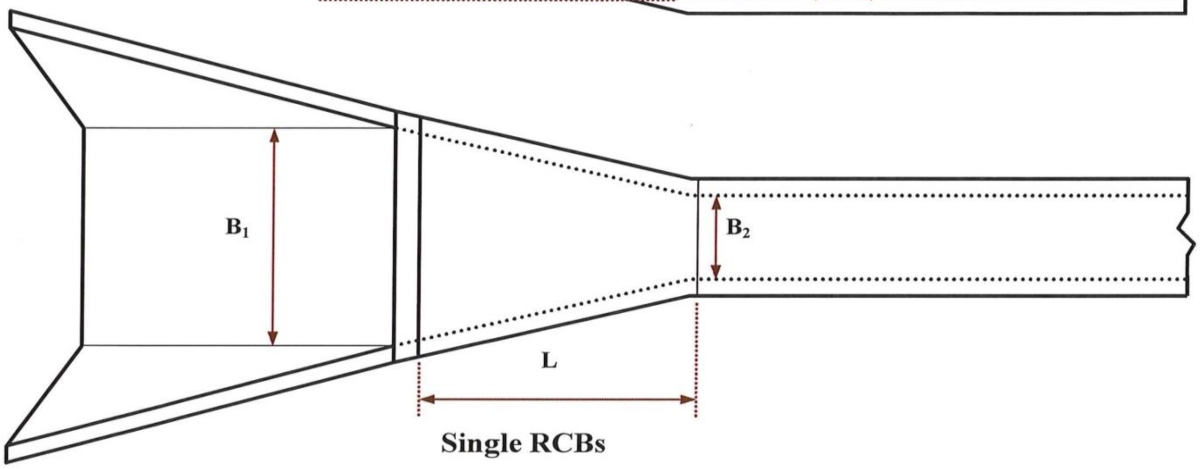
1. Use drop rate (L/Z) of 5:1 (min.)
2. Ratio of barrel width to inlet width (B_2/B_1) should be 60% or greater.
3. L is determined either by (B_1 - B_2) x 4 or Z x 5, whichever is greater. This insures a minimum side taper of 4:1. L should generally be in 5 ft. increments.

Definitions

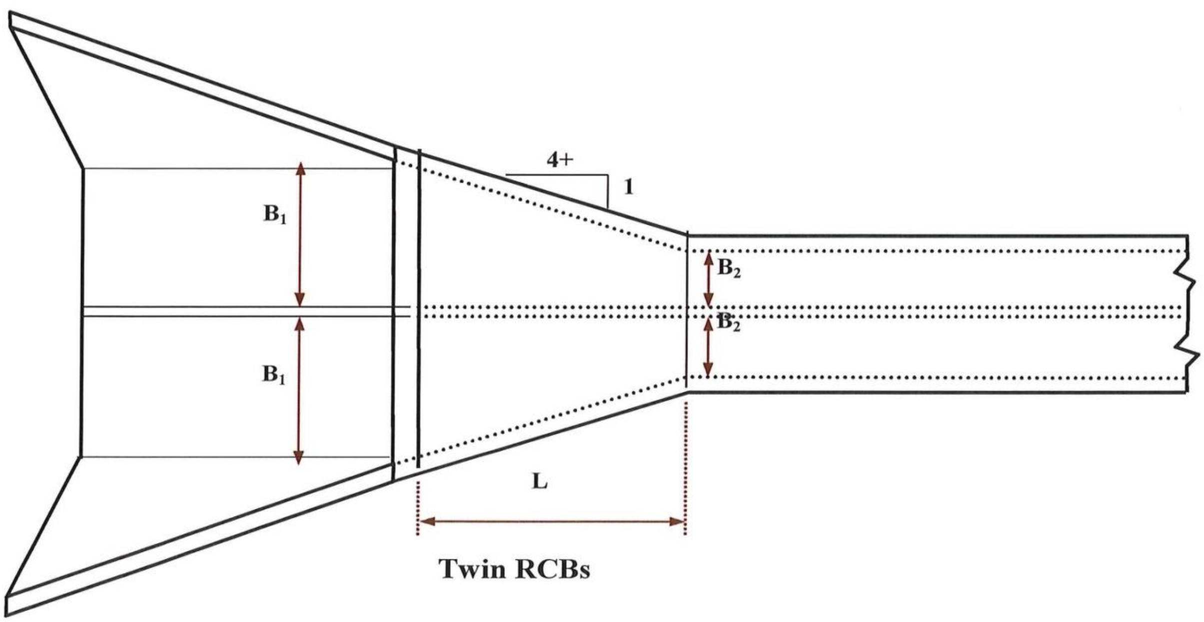
HW -- Headwater from inlet control charts
H_1 -- Specific energy head at inlet
H_2 -- Specific energy head at barrel
B_1 -- Width of inlet opening
B_2 -- Width of barrel opening
D -- Height of opening
H_L -- Energy loss
d_c -- Critical depth
Z -- Drop in flowline required
L -- Length of taper section
S_o -- Slope of barrel
$V^2/2g$ -- Velocity head
N = L/Z = Slope of taper section

Slope Tapered Box Culverts



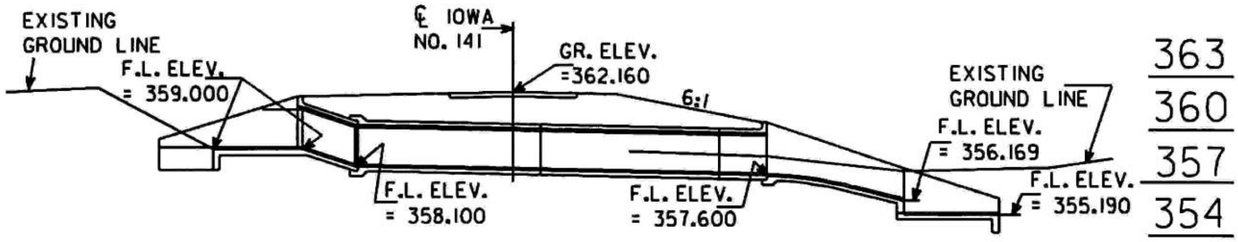


Single RCBs

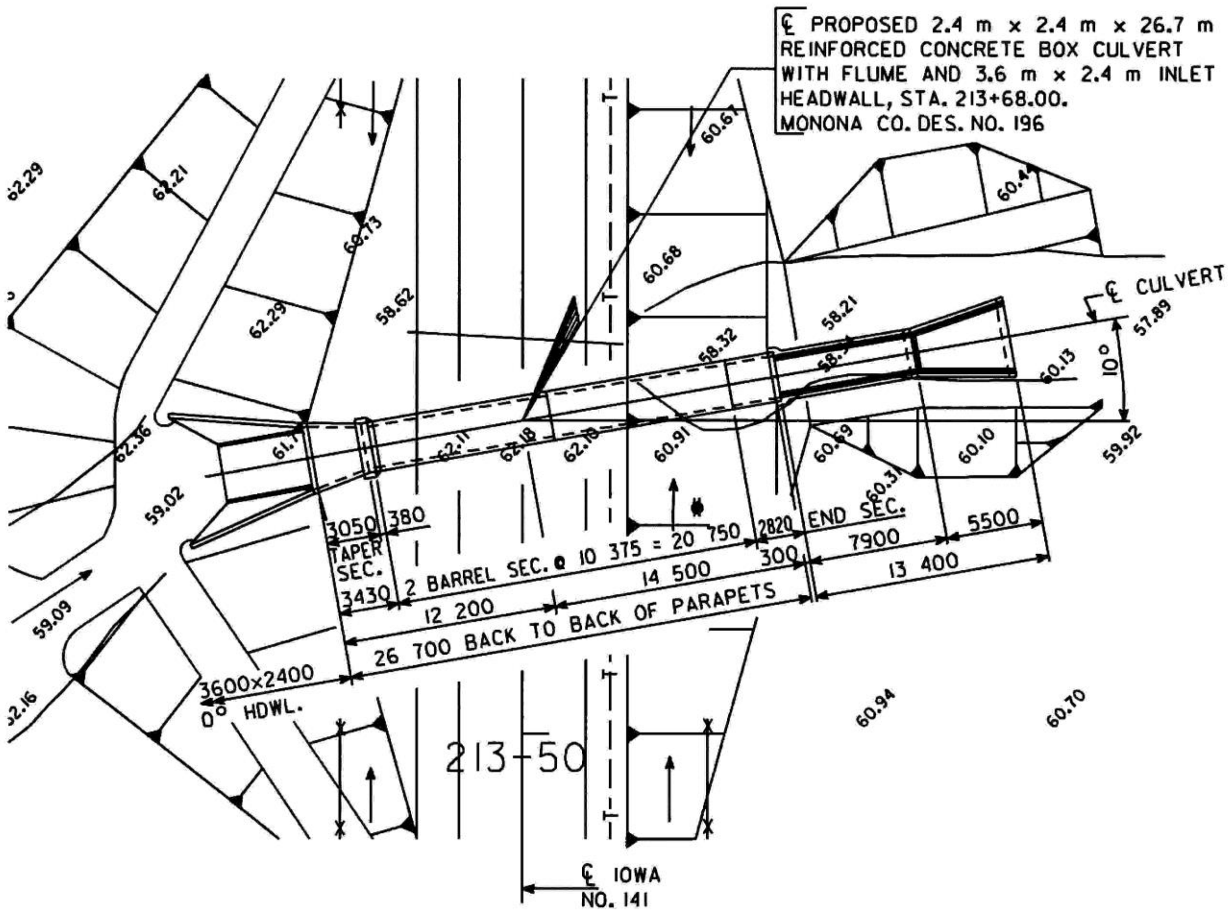


Twin RCBs

Sample Slope Tapered Box Culvert and Flume

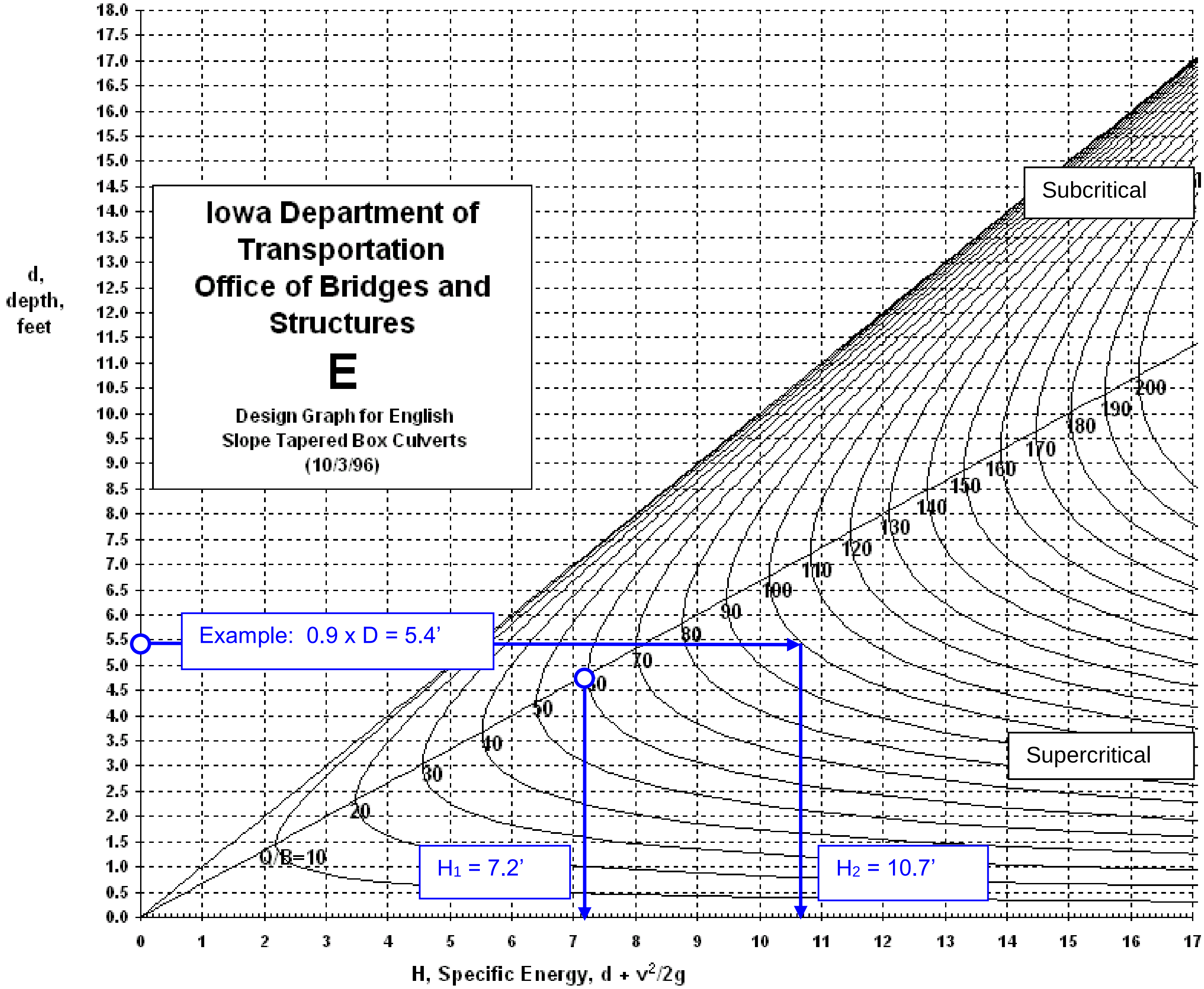


LONGITUDINAL SECTION ALONG ℄ CULVERT



SITUATION PLAN

Design Graph for Slope Tapered Box Culverts



May 29, 1998

Worksheet for Slope Tapered Box Culverts

Project____________________County_______________Des. No._______________

Sta.______________Designer____________Date___________________

Variable	Example	Trial 1	Trial 2	Trial 3	Trial 4
Design Q, ft^3/sec	600				
Inlet Section					
B_1 X D, ft x ft (size of inlet)	10 X 6				
Q/B_1	60				
HW, ft (from HDS #5 nomographs)	7.5				
d_c, ft (from Design Graph)	4.8				
H_1, ft (from Design Graph)	7.2				
Barrel Section					
B_2 X D, ft x ft (size of barrel)	6 X 6				
Q/B_2	100				
0.9 X D, ft	5.4				
H_2, ft (from Design Graph)	10.7				
Slope Tapered Section					
H_L, ft (assumed)	0.2	0.2	0.2	0.2	0.2
Z, ft (= $H_2 - H_1 + H_L$)	3.7				
Selected Z, ft	4.0				
Selected L, ft	12				
Barrel Slope					
d_n = 0.9 X D, ft	5.4				
Min. Slope, % (from HDS No. 3 or Mannning=s eqn.)	1.5				
Is the design acceptable?	Yes				

C4.5.7 Bridge Replacements with RCB's using Flowable Mortar

C4.5.8 Revetment for RCB's

C4.5.9 Grading Control Points

C4.5.10 Stock Passes

C4.5.11 Costs

C4.5.12 Alternative Structure Type

C4.6 Permits and Approvals

C4.7 Submittals